Advanced Materials Research Vols. 356-360 (2012) pp 2820-2832
Online available since 2011/Oct/07 at www.scientific.net
© (2012) Trans Tech Publications, Switzerland
doi:10.4028/www.scientific.net/AMR.356-360.2820

RS & GIS-based Spatialtemporal Analysis of Ecological Footprint and Biocapacity Pattern of Jinghe River Watershed in China: Does Supply Meet Demand?

Dongxia Yue[1, a*], Jinhui Ma[1, b], Jianjun Guo[1, c], Jiajing Zhang[1, d], Jun Du[1, e], Yajie Song[2, f], Cang Hui [3, g]

[1]MOE Key Laboratory of Western China's Environmental Systems, Lanzhou University, Lanzhou, Gansu 730000, China

[2]School of Forestry and Environmental Studies, Yale University, New Haven, CT 06511, USA;

[3]Centre for Invasion Biology, Department of Botany & Zoology, Stellenbosch University, Private Bag X1, Matieland 7602, South Africa;

[a]dxyue@lzu.edu.cn,[b]majh@lzu.edu.cn,[c]guojj2010@lzu.edu.cn,[d]zhangjiajing.jing@163.com,

[e]dujun159@126.com, [f]yajie.song@yale.edu,[g]chui@sun.ac.za

*Corresponding author. TEL: +86-931-8912342; FAX: +86-931-8912342;
E-mail: dxyue@lzu.edu.cn (D.X. Yue)

Keywords: RS; Geographic information system; Ecological Footprint; Biocapacity; Markov Chain Method; Jinghe River Watershed

Abstract. The Ecological Footprint methodology is a framework that tracks Ecological Footprint (humanity's demands on the biosphere) by comparing human demand against the regenerative capacity (Biocapacity) of the planet (WWF, 2010) to advance the science of sustainability. As such, the spatiotemporal dynamics of the Ecological Footprint (EF) and Biocapacity (BC) in a given watershed are important topics in the field of sustainability research based on remote sensing (RS) data and geographic information system (GIS) techniques. This paper reports on a case study of the Jinghe River Watershed using improved EF methodology with the help of GIS and high resolution remote sensing data, to quantitatively estimate the relationship between EF demand and BC supply and analyze their spatial distribution patterns at multiple spatial scales for four periods (1986, 1995, 2000 and 2008). We predict the future BC both overall, and of six categories of biological productivity area for the next four decades using the Markov Chain Method. The results showed that the spatial distribution of EF demand and BC supply were significantly uneven in the region, in which the per-capita EF of all counties located in the watershed increased continually from 1986 to 2008, and the EF per person of counties in the middle and lower reaches area was markedly greater than that in the upper reaches over time. On the supply side, the per-capita BC of all counties decreased gradually from 1986 to 2008, and the per-capita BC of counties in the upper reaches area was greater than that in the middle and lower reaches during the period, causing the uneven spatial distribution of Ecological budget-the gap between supply and demand, showed that the Jinghe River Watershed on the whole has begun to be unsustainable since 2008, with each county exhibiting differential temporal patterns. The prediction results showed that the total BC will increase continually from 2020 to 2050, and the BC of six categories will reduce, indicating that

unsustainability in the region will escalate. As a whole, The EF demand has exceeded the BC supply, and the gap was widening in the Jinghe Watershed. This paper provided an in-depth portrait of the spatiotemporal dynamics of EF and BC, as well as their interactions with humanity and ecosystems.

Introduction

To sustain the regional supply of biocapacity while meeting the human demand on natural resources is a major challenge facing society. In many regions, including Western China, the growing human demand on natural resource supply and changing land use, such as urbanization, are altering biocapacity patterns in the local ecosystems. Thus, the Biocapacity of an ecosystem is the base for maintaining sustainable development and projecting human activities [1, 2, 3, 4], while also setting the ecological limitation for human activities.

The ecological footprint (EF) methodology developed by Rees[5] and Wackernagel [6]which has attracted much attention over the past 10 years, is a resource accounting tool with a biophysical and thermodynamic basis, used to advance the science of sustainability. In the methodology, the EF for a particular population is defined as the total "area of productive land and water ecosystems required to produce the resources that the population consumes, and assimilate the wastes that the population produces, wherever on Earth that land and water may be located" [7]. Rees [5] referred to the EF as the 'appropriated carrying capacity', and biocapacity (BC) is defined as the carrying capacity of local ecosystems to produce useful biological materials and to absorb waste materials generated by humans. Therefore, the two indicators are two aspects of natural resources, demand and supply, where EF represents the "human demand" on the natural resources of a particular population and Biocapacity represents the "natural resource supply" of a particular ecosystem. Thus, the success of EF methodology was probably to a large extent due to the simplicity of the comparison between the supply and demand, which definitively answers the question 'Does Supply Meet Demand?', and suggests a clear distinction between sustainability and unsustainability [8]. The methodology has thus been widely applied at the regional level[9,10,11,12], national level [13,14,15,16] and global level[17,18]. Along with the continuously increasing ecological pressures on our one planet Earth, management of EF (demand) on and BC (supply) will almost certainly be made one of the central concerns of the twenty-first century [19].

However, since the ecological footprint is a relatively new tool, still under development, there is a need to adapt it for more detailed Spatial-temporal analysis and for forecasting the future trend of EF and BC[7, 20]. In a traditional EF study, BC is often measured by the available area of biologically productive land and water based on data reported in national or regional statistics. There is a shortcoming of this methodology: the statistical data often excludes the detail spatial information of the EF and BC as well as the spatial heterogeneity of natural capital and land use [21], in that national and regional statistics are often reported at a coarse resolution which may not be applicable for BC assessment at the level of precision required in order to inform policy making at very fine scales which are not limited by political boundaries [22,10]. Recently the need to develop a new methodology addressing these shortcomings has been recognized [23] especially with regard to developing Remote Sensing (RS) and Geographic Information System (GIS) techniques to provide an effective methodology to resolve spatial problems of ecological research. To avoid the shortcoming, GIS provides a powerful tool to perform spatial analysis, while remote sensing satellite imaging provides a precise data source at fine scales. Using remotely sensed data of land use/cover on the basis of the spatial analytic methods of GIS, the quantitative result of BC can be computed at multiple spatial scales and spatial heterogeneity of BC and the ecological sustainability of a given region can be reflected by a spatially explicit map. In this regard, GIS and remote-sensing data of land use have been used for their ability to provide better estimates to calculate a spatially explicit biocapacity at both coarse and fine scales and analyze the spatial appraisal of EF and BC, as demonstrated by a few case studies [23,24,25,26,27].

On the other hand, EF methodology itself is a static tool without a time variable and therefore cannot be used to quantitatively analyze the past or future development trends of ecological sustainability in a long-time series [11, 28]. However, some cases about the variation trends of EF and BC of a given country or region in a long time series have also been published. For example, Senbel [29] examined several scenarios for human consumption, ecological productivity and material efficiency to explore which variables would have an influence on the ecological budget of North America over the coming century. Yue et al [11] presented two quantitative estimate indices (the change rate and scissors difference) to quantitatively describe the development trends of EF and BC, and analyze the development trends in the past 13 years as well as predicting those in Gansu province (western China) in the following 12 years (1991-2015); The Living Planet Report 2008 [18] predicted that we will need two planets by the early 2030s to keep up with humanity's demand for goods and services if we continue with business as usual. In the Living Planet Report 2010 [30], the Footprint Scenario Calculator made use of the footprint data between 1961 and 2007 as a baseline, and projected the size of each footprint component in 2015, 2030 and 2050 based on the "business as usual" scenario. But none of these methods has provided us with a tool capable of predicting the future regional EF and BC. It is this limitation of the EF framework that is the focus of our paper. We hope that an improved methodology will support local governments in making more sustainable development strategies in the future.

Recently, the Markov Chain Model has been widely used to model and prodict land use/cover changes on the basis of remote sensing (RS) data at large spatial scales[31,32,33,34]. In addition, BC is also an indicator gleaned from land use/cover data and biological productivity (yield) calculated by the EF methodology using GIS. Land use/cover change is therfore one of the major forces driving the development of BC usually[30,35]. It is possible to project the future development trend of BC based on land use/cover change data using the Markov Chain Model combined with the spatial analysis techniques in GIS.

China's West Development Strategy and Grain for Green Project are two important national policies adopted by the Chinese government to help the under-developed western regions to catch up with prosperous eastern regions and protect these environments that have been rapidly degrading since 2000. Along with the growth of the population and economy in recent years, the pressure and impact of human activities on water and land resources have been increasing continually, which causes the conspicuous conflict between too much human demand on natural resources and their insufficient supply in this region. Therefore, based on EF methodology, we have selected the Jingh River Watershed in northwestern China as a study case for a discussion of the spatial-temporal distribution patterns of EF and BC and their gap at multiple spatial scales using RS date from the years of 1986, 1995, 2000 and 2008, The study will reflect the status of ecological sustainability in the region more comprehensively. In addition, we forecast the future development trend of BC in the watershed as a whole over the next fourty years using the Markov Chains Model, which has key scientific implication and practical application. This study thus refines the current EF methodology to improve the accuracy of BC assessment.

Study Area

The Jinghe River Watershed (see Fig. 1) is a mountainous watershed located in the middle-western Loess Plateau, northwestern China, between 106°14′~108° 42′E and 34° 46′~37°19′N, and about 1200 m above sea level. It consists of 31 counties of the Ningxia Hui Autonomous Region, Gansu Province and Shannxi Province, covering an overall area of 44 982.54km2, while the population is 63.48×105 in 2008. The topography of the watershed is high in the northern part (upper reaches) and low in the southern part (lower reaches), with Liupan Mountain on the west side and Ziwu Mountain on the east side. The Jinghe River and its tributaries all cut deeply into the loess landscape [36]. The annual average precipitation in the area is between 350 and 600 mm, and gradually decreases from southeast to the northwest. However, the precipitation is mainly concentrated in July, August, and September. The rainfall in these 3 months often accounts for 60–70% of total annual precipitation, most of which is in the form of high intensity storms, therefore soil erosion predominately occurs during this period. The vegetation cover in this region is relatively low. For several decades, natural vegetation in the region has been severely degraded. Presently, forest cover is on average only 6.5%, and can even be as low as 3% in some areas. Grass cover is only 25–65%. The forest boundary of Ziwu Mountain has receded 20 km since the 1950s; both runoff and sediment have increased significantly[37].

The Jinghe River Watershed is strategic to the development of northwestern China, providing an important water source for irrigation of the Guanzhong Plain, the food bowl for the country downstream. Over the last three decades, the local population increased rapidly and has greatly impacted land resources in the area so that the significant change of EF and BC has occurred during this time scale, which has in turn influenced the sustainable development of local eco-economic systems. The impact in the area, due to increased demand, has drawn increasing attention from Chinese academics, planners, and decision makers.

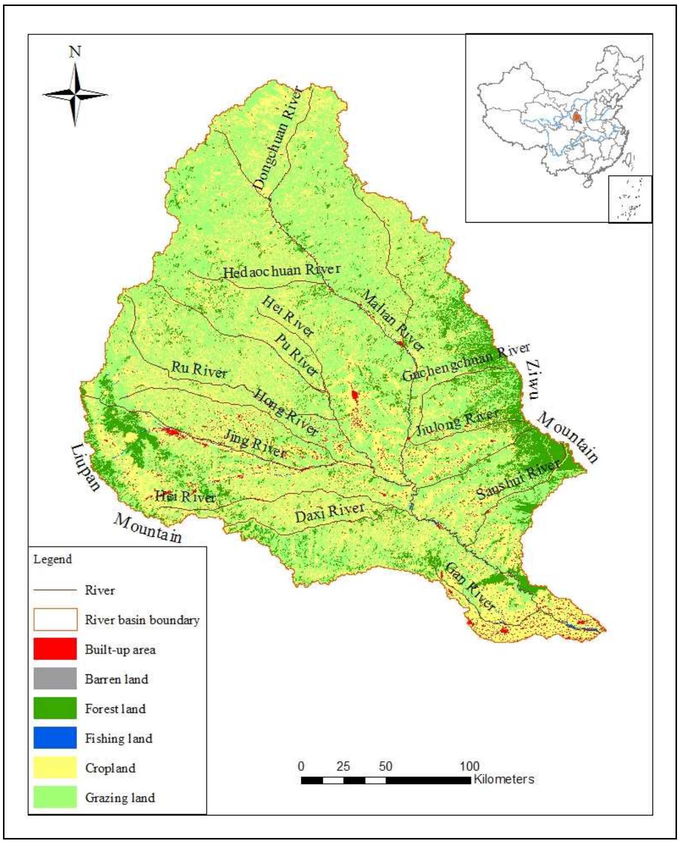


Figure. 1 Studying area: Jinghe River Watershed, China.

Method

Methodologies. For a given region, EF methodology provides a comprehensive method for evaluating whether or not human demands remain within the region's regenerative BC as a minimum condition for sustainability [38]. In many cases, the ecological budget - the gap between BC and EF - is an important quantitative indicator of the extent of sustainable development. The concept of ecological budget (EB) is defined as the sum of BC minus the sum of EF [29]. If the ecological budget is negative, it is often interpreted as an 'ecological deficit' [8], in which human consumption exceeds the BC in a given region and making the area unsustainable. In a reverse situation where the ecological budget is positive and human consumption is within the BC, the state is called an 'ecological surplus', meaning the region is sustainable.

The conventional EF methodology often uses "global hectares" (gha) as a standard unit that represents biologically productive areas with the world average productivity to quantify the EF and BC, weighing by the equivalence, yield, and fossil-energy conversion factors [13]. Therefore, EF （demand） and BC （supply ）become directly comparable with each other across the globe. In this study, biologically productive areas are categorized into six main categories (cropland, grazing land, fishing ground, forest, built-up area and carbon-uptake land in EF calculation or barren land in BC calculation) [23] and calculated using a weighted sum (in global hectare). Furthermore, we simply considered the biocapacity of barren ground (including exposed soil, sand, rocks, snow or ice with less than 10% vegetation cover throughout the year) to be zero in the BC calculation due to its extremely low productivity[23].

In our study, remote sensing images (Landsat TM) were used to gather land use/cover data (information). GIS is used for calculating the spatial data of BC supply, analyzing and mapping the spatial-temporal pattern of EF and BC. All geo-related analyses were conducted using commercial software (ArcGIS 9.2, ESRI). The Markov Chain Model is used to project the BC of six categories of biological productivity area on the basis of land use/cover change data for the next 40 years. The calculation of EF follows the conventional EF method [13, 23] and the Markov Chain Model [34] is a mathetical tool in common use so that there are no additional introductions in the paper.

Data analysis and calculation

Eco-footprint(Demand on biocapacity). Based on the conventional EF methods, we calculated the EF and related indices in 1986, 1995, 2000 and 2008 at Jinghe River Watershed at both overall and county scales. All social statistics data were taken from relational yearbooks published by China Statistics Press and the FAO Production Yearbook published by the Food and Agriculture Organization of the United Nations. The imports and exports connected with the Jinghe River Watershed at a geographic scale include those: (1) from the region to other nations in the world; (2) among different regions within China. The first section of data can be taken from yearbooks, however the second set of data is very difficult to attain. We therefore calculated the EF from a ratio of per person consumption to total population consumption of natural resources and hereby avoided errors caused by a lack of imports and exports data in the region (see figure 2). The equivalency and yield factors were both calculated according to the average yield of every county and the global level in 1986, 1995, 2000 and 2008. The equivalency and yield factors for the barren ground were also regarded as zero. The conversion factor of fossil-energy footprints was kept constant across all areas as suggested by Wackernagel et al. [13]. The map of spatial distribution of per capita EF of all counties was produced based on the county-level administrative map in the region using ArcGIS (see figure3). Following the map and data above, we will analyze the spatial distribution pattern of EF at the two scales.

Biocapacity (supply). Biocapacity in the Jinghe River Watershed was calculated using the spatial data of land use/cover in 1986, 1995, 2000 and 2008 as a base layer for the GIS analysis. The vector map of land use /cover of Jinghe River Watershed was derived from Landsat TM images (30m×30m) (1986, 1995, 2000 and 2008), assisted by field surveys at the scale of 1:100000 from interpretation of the remote sensing images. Landuse types are determined using the Global Land Cover Classification (Hansen et al., 1998). The administrative vector map of counties in Jinghe River Watershed is used as a main resource for map presentation, with the same resolution as the vector map of land use /cover, provided by the Environment and Ecological Science Data Center on a 1:100000 scale. By comparing the data from the Landsat TM image with the field survey data, the overall accuracy of the land use maps for the four times was greater than 87%, suggesting a robust input for the calculation of biocapacity in Jinghe River Watershed.

Analyses were made at two different scales (based on land use/cover unit) using ESRI ArcGIS 9.2. The map of BC at Jinghe River Watershed scale was developed using a new attribute table in ArcGIS of the product of equivalency and yield factors at the land use unit (namely the absolute value of biocapacity). The county level administrative maps were then overlaid on the BC map when calculating the BC. Based on the absolute value of BC and the social statistics data for all counties, we then developed the maps of per-capita EF and BC at county scale (see figure 3-5). It was assumed that 12% of the biologically productive area of BC should be preserved for biodiversity protection [13] and this area was deducted from all biologically productive area types. Furthermore, the spatial-temporal pattern of EF and BC and related indices were simultaneously analyzed at different geographic scales.

Biocapacity prediction using the Markov Chain Model. The Markov Chain Model was used to analyze the stochastic nature of the land use data. Biocapacity prediction is mainly to project land use change using the Markov Chain Method in the final analysis. In the paper, based remote sensing data and using ArcGIS 9.2 (ESRI), the detailed processing procedure is as follows:

(1)The land change/conversion matrix for three periods (1985-1995, 1995-2000 and 2000-2008) were derived by overlay spatial data of land use/cover; And subsequently land change/conversion transitional probabilities matrix of three periods were estimated.

(2)The transition probabilities of 2000-2008 (the last period), which has been tested for time independence and time stationary[34], was assumed to be Markov transition matrix P and used to predict the future land use category distribution for 2020, 2030, 2040 and 2050, using the Markov Chain Model and with the help of MATLAB software. We therefore obtained the stable value of land use/cover change which was used to calculate BC in Jinghe Reiver Watershed for the next four decades.

(3)Finally, the future BC in the Jinghe River Watershed as a whole was calculated over the next four decades by employing the EF methodology. The equivalency and yield factors of 2008 were used as a constant and 12% of BC was also deducted for all land use types over time in the prediction. The results of this prediction are shown in Table 1.

Results and Discussion

Past development trend of EF and BC time series in Jinghe River Watershed. Fig.2 shows the whole development trend of per capita EF (demand) , BC (supply) and the gap between them (per capita EB) in the Jinghe River Watershed in the four time periods.The per capita EF (demand) in the watershed increased from 1.02 gha in 1986 to 1.77 gha in 2008. On the supply side, the per capita BC had been reduced from 2.32 gha in 1986 to 1.72 gha in 2008. The per capita EB was positive during the period 1986-2000, indicating an ecological surplus in the region, showing that the state of ecological development was self-sustainable in the period; however, the per capita EB has been negative since 2008, meaning that the watershed as a whole passed the point at which the annual EF matched the annual BC— that is, the regional human population began consuming renewable resources faster than ecosystems can regenerate them and releasing more CO_2 than ecosystems can absorb. This situation is also called "ecological overshoot" i.e. an unsustainable state of ecological development. A comparison of the results with those published[13,30] in the Living Planet Report 2010 showed that the watershed was considered as a national unsustainable area because its per capita EF was greater than China's per capita BC in 2008, and a global sustainable area in that its per capita EF was still less than the global per capita BC. Therefore, we must answer the questions: "What will the future hold?", and "What actions can be taken to end ecological overshoot and so achieve sustainability?"

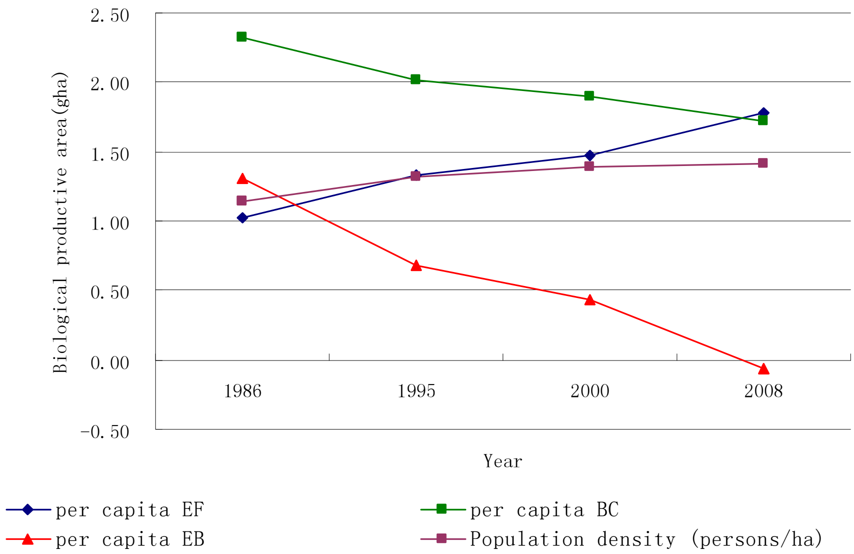
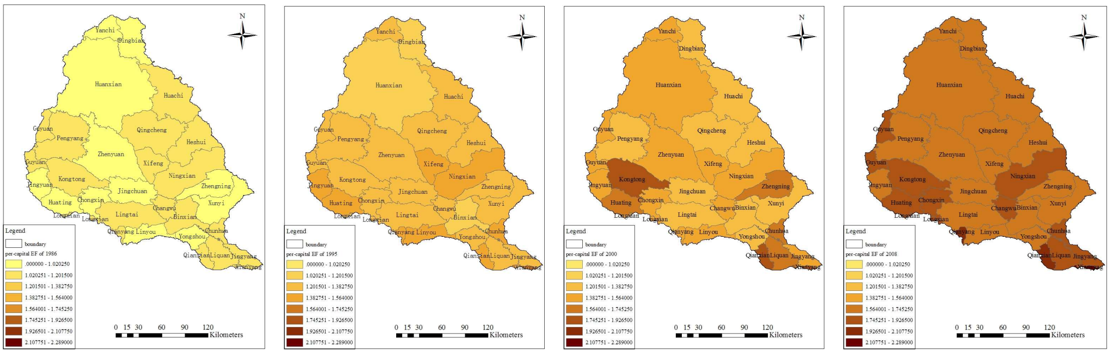


Figure. 2 The development trend of per capita EF, BC and EB for Jingher River Watershed 1986-2008. The per capita EB has declined quickly with increasing population density, becoming negative in 2008.

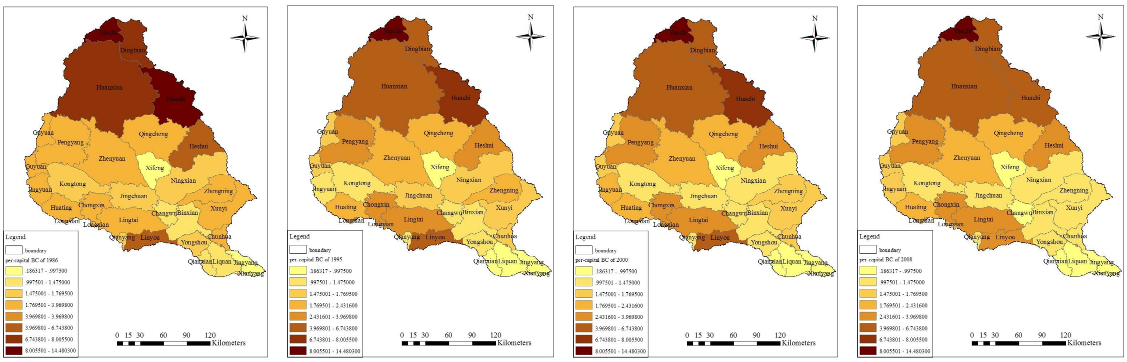
Spatiotemporal distribution analysis of EF, BC and EB at county scale. As can be seen from Fig. 3, 4 and 5, with the help of the GIS technique, the maps of EF, BC and EB have been produced in the watershed at county scale for1986, 1995, 2000 and 2008, showing the overall spatiotemporal patterns and trends of EF, BC and EB, which reflect the comprehensive state of ecological sustainability for the watershed over time. In the three maps, different grades of color correspond to different thresholds of per capita EF, BC and EB, in order to make an annual comparison of them for different years. From the maps of Fig. 3, when comparing the different grades of color for different counties, we noticed that the spatial patterns of per-capita EF are unevenly distributed holistically, and the per-capita EF of counties in the middle reaches area and the lower reaches area (the southern alluvial plain) were markedly greater than those in the upper reaches area (the hilly *Loess Plateau region*). The per-capita EF of all of counties increased continually from 1986 to 2008 because the whole color becomes continually deeper when comparing the 4 annual maps. Specifically, per-capita EF of counties in the middle reaches area increased at a more rapid rate than at other counties while the EF per-capita of the counties in the lower reaches areas was consistently the greatest among them all - showing that the standard of living varied, and that human demand on natural resources is unevenly distributed in the region.



a.1986 b.1995 c.2000 d.2008

Figure. 3 Distribution of per-capita EF of all counties in Jinghe River Watershed for four time periods. the deeper the color, the higher the EF per person

On the supply side (Fig.4), the per-capita BC was also uneven in the region. The per-capita BC of counties in the upper reaches areas was markedly greater than the counties in the middle and lower reaches areas. The per-capita BC of all of counties decreased continually from 1986 to 2008 as can be seen by the steady lightening of the map over the four years. Specifically, the BC per person of counties in the upper reaches area changed with a faster decline rate than other counties and accounted for the biggest drop among all of counties every year in the region. All of results showed that although the differences of BC supply were caused by different geographical characteristics, environmental conditions and land use as well as land cover[37], yet differing the BC per person was caused mostly by population density: accounting for is why the lower reaches area had the lowest BC per person in the watershed in every annual map. The results suggested that spatial distribution patterns of BC per person (supply) were apparently different from those of EF per person (demand) supply at the county scale.

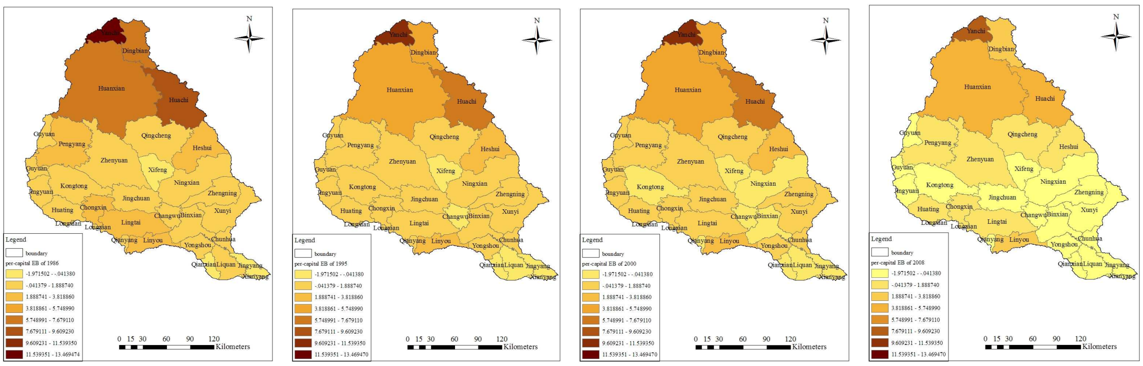


a.1986 b.1995 c.2000 d.2008

Figure. 4 Distribution of per-capita BC of all counties in Jinghe River Watershed for four time periods. (The deeper color represents a higher BC per person).

Figure 5 shows the per-capita EB displayed a great variation in the different geographical areas. We can see the development trends of spatiotemporal patterns of per capita EB by comparing the 4 annual maps in the spatiotemporal dimension. The uneven spatial distribution of EB is visible in the region, showing there were different ecological conditions for all of counties located in the watershed. The map as a whole continually becomes lighter over the four year period, indicating that the per capita EB of the Jinghe River Watershed as a whole was being reduced during the three decades, which was consistent with the results from the two indices above. There were 4, 8, 10 and

17 counties among 31 counties reported unsustainable in 1986, 1995, 2000 and 2008, respectively, showing the proportion of unsustainable counties increased over time. More than half of all counties were in ecological overshoot by 2008, showing where natural resource supply did not met humanity`s demand. Therefore, development trends of every county and the watershed as a whole were placing great strain on the environment.



a.1986 b.1995 c.2000 d.2008

Figure. 5 Distribution of per-capita EB of all counties in Jinghe River Watershed for four time periods. (The deeper color represents a higher EB per person).

BC prediction in Jinghe River Watershed for next four decades. In Table 1, Fig. 6 and Fig.7, the prediction results show a dynamic window for BC supply of Jinghe Rive Watershed in the coming 40 years, showing the total BC by 2050 will be down to 96.332×10^5 gha, which will only accounts for 85.53% of the total EF demand on the assumption that both humanity`s demand and biological productivity are same as in 2008. So, total ecological overshoot will be at least 16.3×10^5gha, indicating that unsustanability in the region will maintain a growth trend. However, the future of BC among the six categories of biological productivity area is expected to be different, with the BC of cropland and fishing ground expected to reduce rapidly, while that of forest, grazing, and built-up areas, is actually expected to increase slowly over time.

Table 1 Prediction of BC of six categories of biological productivity area at the stable state in Jinghe River Watershed for next four decades

Year	Built-up area [10^5gha]	Barren ground [10^5gha]	Forest [10^5gha]	Fishing ground [10^5gha]	Cropland [10^5gha]	Brazing land [10^5gha]	Total BC [10^5gha]
2020	3.767	0.00	4.492	0.032	95.645	4.237	108.173
2030	3.813	0.00	4.672	0.029	90.815	4.377	103.706
2040	3.832	0.00	4.849	0.027	86.575	4.498	99.781
2050	3.829	0.00	5.022	0.026	82.854	4.601	96.332

The partition of the biocapacity (see Fig.6) indicated that the six major categories of biologically productive area will make different contributions and have an imbalance over the next four decades. The BC of cropland as a significant portion will account for more than 82% of the total although it shows a decreasing trend over the period 2020-2050. The contributions of fishing ground to the BC during the periods will be extremely low (<0.03%), showing that water resource will still be scarce in Jingher Rever Watershed and a limiting factor for increasing biocapacity in this sector. The contribution of grazing land, forest and built-up area will be between 3% and 6% with an increasing trend, showing that the increase of grazing land and forest areas will positively reflect BC supply in the future.

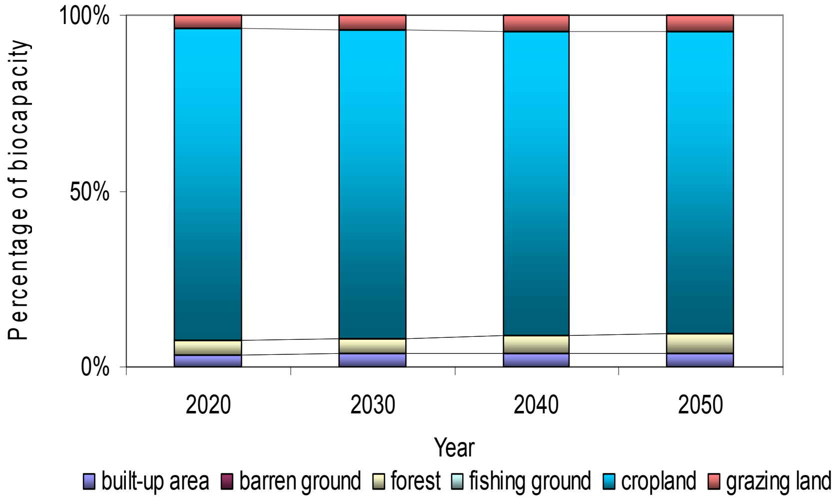


Figure. 6 The percentage of BC of six categories of biological productivity area in Jinghe River Watershed for next four decades

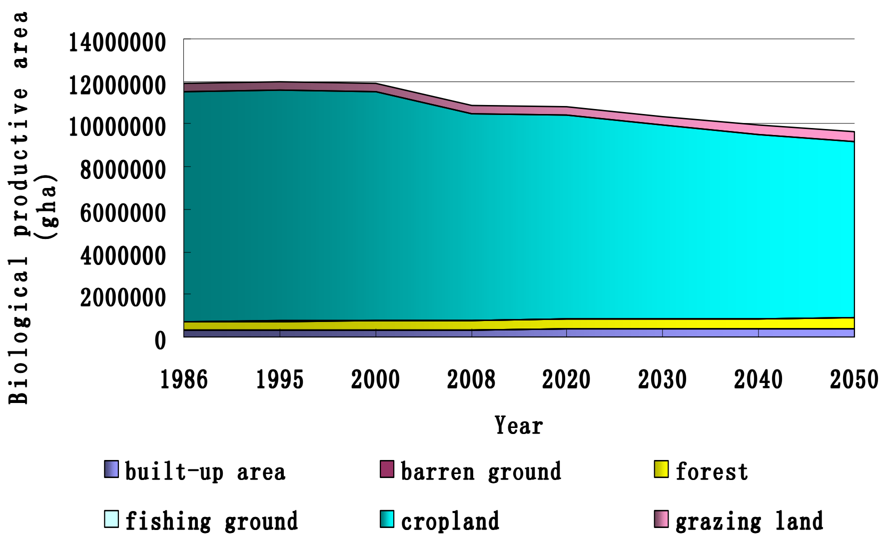


Figure. 7 The development trend of BC of six categories of biological productivity area in Jinghe River Watershed for 1986-2050

Conclusion

Overall, the results shown above in Table 1 and Fig.2-7 reflect the whole spatiotemporal patterns and trends of ecological sustainability of Jinghe River Watershed from 1986 to 2050, of which the demonstrative calculation offered insight and vital information on the past and future trends of regional EF and BC in the long term. Indeed, with the increase of regional population, the improvement of living standards, the change of consumption behavior, and the growth of a high-risk dependency on trade and extra-territorial land BC [39,40,11], humanity`s demand on natural resources (EF) in the areas is expected to surpass supply. Soil degeneration in the area has resulted in water loss and soil erosion is expected to accelerate in the region in the coming years so that the biological productivity (crop yield) will also be reduced [36]. Research findings from the International Food Policy Research Institute (IFPRI) indicate that climate change will cause yield declines for the most important crops [41]. Therefore, the imbalance between EF demand and BC supply in the coming years may well become even greater than our predictions, a change that no-one would wish for.

The results help us better understand the ecological significance of EF demand and BC supply and the gap between them, and help provide theoretical approaches to make policies of sustainable development at multiple spatial scales. At a broad scale, the watershed was on a relatively unsustainable development route, but the county-scale revealed huge spatial heterogeneity. Therefore, the innovative eco-economy strategies should be made not only based on our spatial-temporal analysis result of EF and BC, but also based on information with detailed spatial heterogeneity of the EF and BC derived here at multiple spatial scales in the region. Therefore, it is time to control the increase of population, optimize the consumption pattern of human beings, improve energy efficiency, protect the environment, advance cropland technologies, enhance the productivity of natural and agricultural ecosystems, reduce carbon emissions and so on, helping to increase BC supply as well as reduce the EF demand. Thus, the supply should once again meet the demand and bring local inhabitants out of ecological overshoot and onto a potentially sustainable path for the whole Jinghe River Watershed and all its reaches. We believe the gap between EF demand and BC supply can be changed acceptably by developing and practising a set of fitting policies in all geographic areas.

Many crucial questions pertinent to building a sustainable society can be addressed by EF research. These include measuring EF and BC at global, national and regional levels, identifying the level of ecological overshoot and tracking progress toward ecological sustainability [20]. The unevenness of EF and BC distribution is a universal and objective phenomenon. The analysis of their spatial distribution at coarse scales inevitably overlooks the inner characteristics of biocapacity, which can only be reflected at fine scales. Towards this end, the estimation and analysis at a fine geographical scale is necessary as a complementary method, and the spatiotemporal pattern and development trend analysis of EF and BC at multiple spatial scales is valuable both in assessing the past and in predicting the future. Our research work also suggests that RS data, GIS technique and the Markov Chain Method are useful for overcoming the limitations of the conventional EF method for past and future spatial-temporal analysis of EF demand and BC supply patterns. Particularly, the GIS-based calculation of the biocapacity using remote-sensing data of land use proved to be time-efficient, resulted in high resolution information and was more accurate than that using social statistical data alone[11]. In the paper, we provided an improved EF method, especially regarding prediction methods. The analytic results were still not precise enough to obtain a complete understanding of EF demand and BC supply balance in the future, because of the assumption that the past factors will continue to influence the future in a linear fashion. Compounding effects have not been taken into account. Further efforts should be paid on collecting more detailed data to predict regional EF with consideration of the change of the population, consumption behaviour and foreign trade status, and improving the accuracy of BC prediction using the Markov Chain Model with consideration of bioproductivity and climate change and other influencing factors. In short, with the proposed research initiatives, the problems surrounding sustainability can be analyzed in greater depth so that stakeholders would be aided in planning for ecological sustainability and monitoring sustainable development in order to put us on a more sustainable trajectory for the future.

Acknowledgements

This work was supported by the National Natural Science Foundation of China (No. 41021091, 40671179 and 70873053), the Program for New Century Excellent Talents in University (NECT-09-0449), the National Key Technology R&D Program of China (No. 2011BAK12B05,06 and 08), and the Chinese 111 program of the Ministry of Education. We are grateful to Emily Derbyshire for her kind help with the English wording of this manuscript, anonymous reviewers and the editor for constructive comments and suggestions.

References

[1] J.X. Gao: Exploration of Sustainable Development Theory–Theories and Application of Ecological Carrying Capacity (Chinese Environmental Science Press, Beijing 2001) (in Chinese).

[2] D.I. Carey: Global Environmental Change Vol. 3(2) (1993), p. 140.

[3] I. Scoones, in: Economics and Ecology: New Frontiers and Sustainable Development. edtied by E.B.Barbier, Publications/Chapman & Hall, London(1993).

[4] M. Sagoff: Bioscience Vol. 45(9)(1995), p.610.

[5] W.E. Rees: Environ Urbanization Vol. 4(1992), p.121.

[6] M. Wackernagel and W.E. Rees: Our Ecological Footprint, Reducing Human Impact on The Earth (New Society Publishers, Philadelphia 1996).

[7] W.E. Rees: Ecological Economics Vol. 32 (3) (2000), p.371.

[8] H.Haberl, K.H. Erb and F. Krausmann: Ecological Economics Vol. 38(2001), p. 25.

[9] G.W. McDonald and M.G. Patterson: Ecological Economics Vol. 50(2004), p.49.

[10] B. Chang and L. Xiong: J Geog Sci Vol. 15(1)(2005), 44–52.

[11] D.X. Yue, X.F. Xu, Z.Z. Li, H. Cang, W.L. Li, H.Q. Yang, J.P. Ge: Ecological Economics Vol. 58(2006), p.393.

[12] M. Kissinger, J. Fix and W.E. Rees: Ecological Economics Vol.62(2007), p.552.

[13] M. Wackernagel, L. Onisto, P. Bello, C. L. Alejandro, S. L. F. Ina, M.G. Jesus, I. S. G. Ana and G. S. G. Ma.: Ecological Economics Vol. 29(3)(1999), p.375.

[14] M. Lenzen and S. Murray: Ecological Economics Vol. 37(2001), p. 229.

[15] D.Van Vuuren and E.M.W.Smeets: Ecological Economics Vol. 34(2) (2000), p.115.

[16] M. Wackernagel and A. Galli: International Journal of Ecodynamics Vol. 2(1)(2007), p.1.

[17] T.J. White: Ecological Economics Vol. 64(2)(2007), p. 402.

[18] WWF (World-Wide Fund for Nature) International, Global Footprint Network, ZSL (Zoological Society of London): Living Planet Report 2008(WWF, Gland, Switzerland 2008) (www.panda.org/livingplanet).

[19] J. Kitzes, M.Wackernagel, J. Loh, A. Peller, S. Goldfinger, D. Cheng and K. Tea: Philos Trans R Soc Lond B Biol Sci Vol. 363(1491) (2008), p.467.

[20] M.Wackernagel and J.D.Yount: Environment, Development and Sustainablitiy Vol. 2(2002), p.21.

[21] K.H.Erb: Land Use Policy Vol. 21(2004), p.247.

[22] A.L. Mayer: Environment International Vol. 34(2008), p.277.

[23] D.X. Yue, X.F. Xu, C. Hui, Y.C. Xiong, X.M. Han and J.H. Ma: Ecological Economics Vol. 70(2011), p. 988.

[24] J. Kitzes, A. Galli, M. Bagliani, J. Barrett, G. Dige, S. Ede, K. Erb, et al. : Ecological Economics Vol. 68(2009), p.1991.

[25] M.A. Luck, G.D. Jenerette, J.Wu and N.B. Grimm: Ecosystems Vol.4(2001), p. 782.

[26] G.D. Jenerette, W.A. Marussich and J.P. Newell: Ecological Economics Vol. 59(2006), p.38.

[27] D.Moran, M. Wackernagel, J. Kitzes, B.W. Heumann, D.Phan and S.H. Goldfinger; Ecological Economics Vol. 68(2009), p.1938.

[28] C. Hui, R.Veldtman and M.A. McGeoch: Ecography Vol. 33(2010), p.95.

[29] M.Senbel, T. McDaniels and H. Dowlatabadi: Global Environmental Change Vol. 13(2003), p.83.

[30]WWF (World-Wide Fund for Nature) International, Global Footprint Network, ZSL (Zoological Society of London): Living Planet Report 2010(WWF. Gland, Switzerland 2010) (www.panda.org/livingplanet).

[31] J.R. Drewett: Reg.Stud. Vol. 3(1969), p.269.

[32] S.Jahan: Socio-Econ. Plan.Sci. Vol. 20(1986), p.243.

[33] R.M. Muller and J.Middleton: Landscape Ecol. Vol. 9(1994), p. 151.

[34] Q.Wu, H.Q. Li, R.S. Wang, J. Paulussen, Y. He, M. Wang, B.H. Wang, Z. Wang: Landscape and Urban Planning Vol. 78(2006), p.322.

[35] D.X.Yue, J.H. Ma, J.Gong, Y.C. Xiong, Y.J. Song : Journal of Lanzhou University (Natural Sciences) Vol. 45(6)(2009), p.68 (in Chinese).

[36] A.N. Suo, Y.C. Xiong, T.M. Wang, D.X. Yue, J.P. Ge: EcoHealth Vol. 5(2)(2008), p.127.

[37] D.X. Yue, J, Du, J.Y. Liu, J.J. Gou, J.J. Zhang, J.H. Ma: Acta Ecologica Sinica Vol. 31(9) (2011), p.2550

[38] C. Monfreda, M. Wackernagel and D. Peumling: Land Use Policy Vol. 21(2004), p.231.

[39] M. Kissinger and W.E. Rees: Ecological Economics Vol. 68(2009), p.2309.

[40] M. Kissinger and W.E. Rees: Land Use Policy Vol. 27(2010), p.589.

[41] G.C.Nelson, M.W.Rosegrant, J. Koo, R.Robertson, T. Sulser, T. Zhu, C. Ringler, S. Msangi, A. Palazzo, M. Batka, M. Magalhaes, R.Valmonte-Santos, M. Ewing and D. Lee: Climate change: Impact on agriculture and costs of adaptation (International Food Policy Research Institute, Washington, D.C. 2009).

Progress in Environmental Science and Engineering
10.4028/www.scientific.net/AMR.356-360

RS & GIS-Based Spatialtemporal Analysis of Ecological Footprint and Biocapacity Pattern of Jinghe River Watershed in China: Does Supply Meet Demand?
10.4028/www.scientific.net/AMR.356-360.2820